NSTX

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New δf Particle Code for Calculation of Non-Ambipolar Transport and NTV

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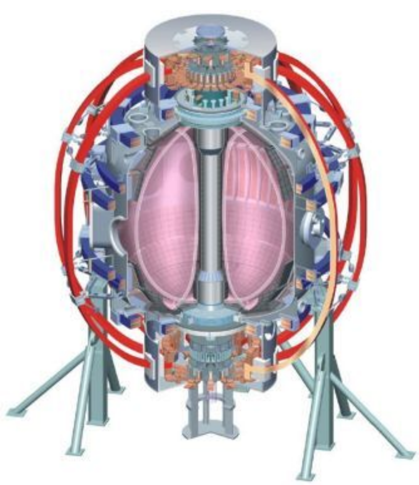

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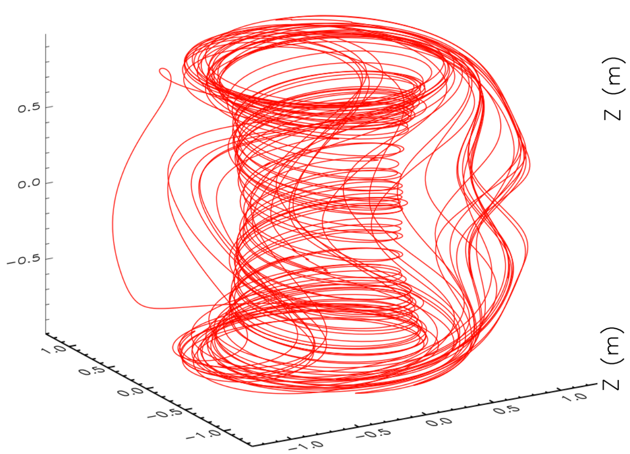
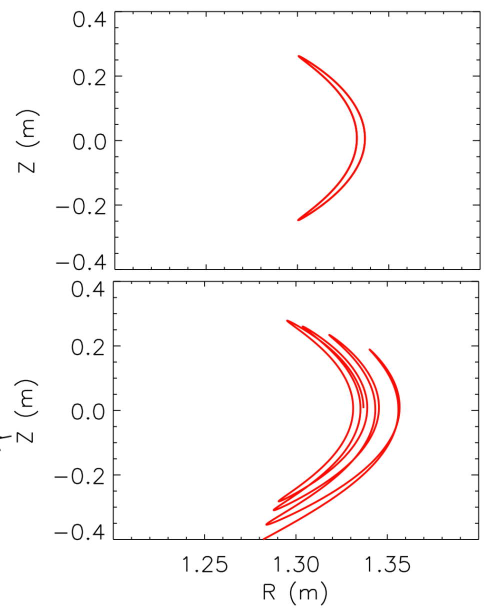
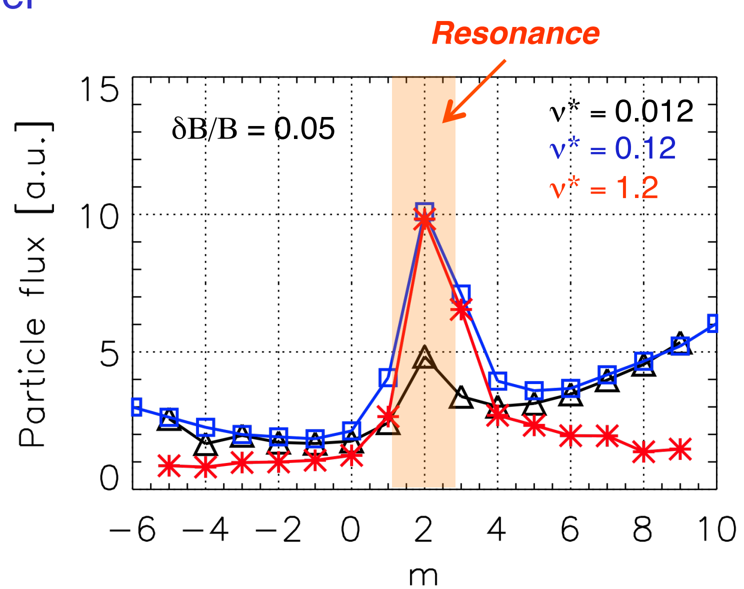
POCA is drift-kinetic δf particle code to calculate neoclassical transport with 3D magnetic perturbations

- POCA (Particle Orbit Code for Anisotropic pressures)
  - Follows guiding center orbit motions in (ψ, θ, ϕ, $v_{||}$) space
  - Solves Fokker-Plank equation with modified pitch-angle scattering collision operator conserving toroidal momentum
  - Calculates local neoclassical quantities: Diffusion, flux, bootstrap current
  - Directly calculates anisotropic tensor pressure and NTV
  - Uses IPEC type routines, ready for 2D or 3D equilibrium coupling, and parallelized
  - Designed to easily handle 3D magnetic field information: 2D equilibrium from EFIT, ESC and 3D perturbation from IPEC and analytic model

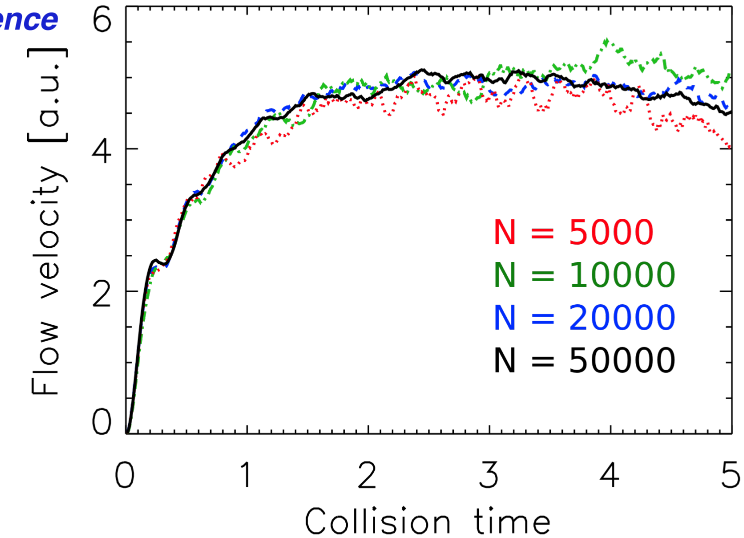




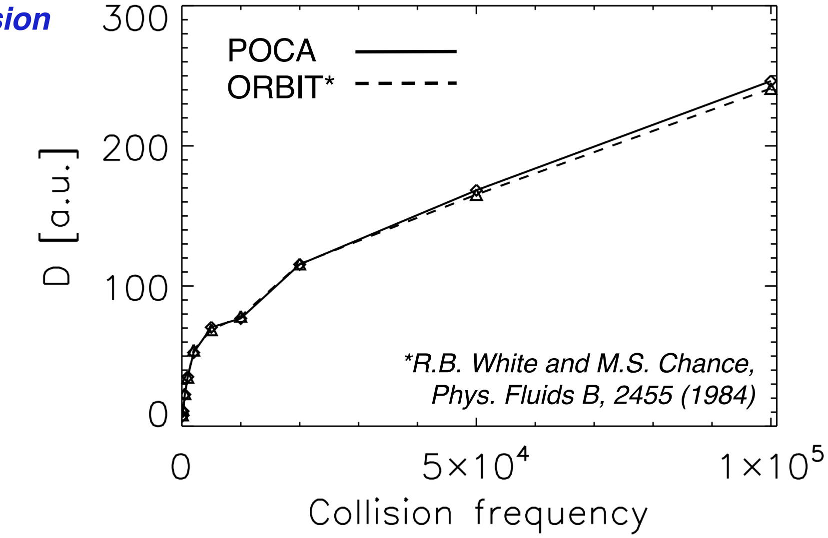


POCA is being successfully benchmarked

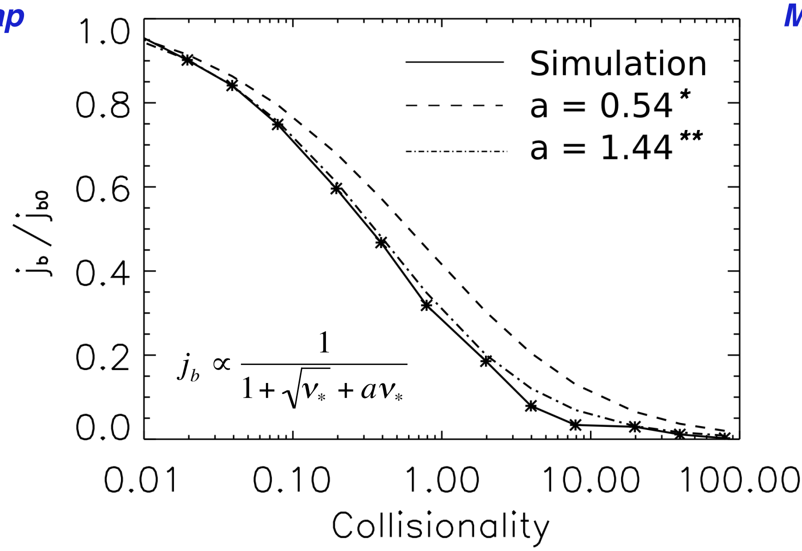
Convergence



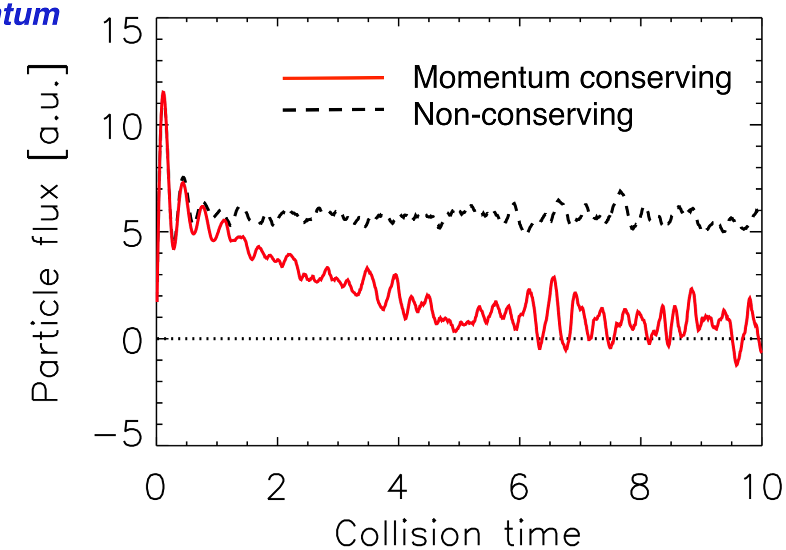
Diffusion



Bootstrap current



Momentum



**F.L. Hinton and M.N. Rosenbluth, Phys. Fluids 16, 836 (1973)*

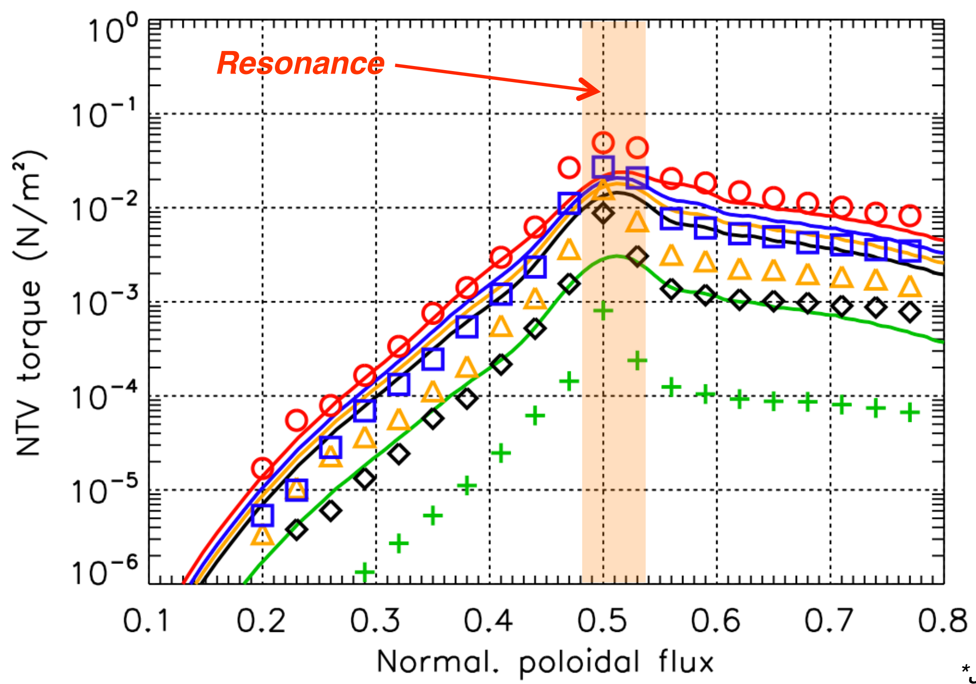
***M. Sasinowski and A.H. Boozer, Phys. Plasmas 2, 610 (1995)*

Now, NTV calculation has been implemented in POCA

- NTV is calculated by anisotropic pressures and magnetic field spectrum

$$\frac{\delta B}{B_0} = \delta_{mn} \sum \cos(m\theta - n\phi) \longrightarrow \left\langle \hat{\phi} \cdot \nabla \cdot \vec{P} \right\rangle = \left\langle \frac{\delta P}{B} \frac{\partial B}{\partial \phi} \right\rangle = B_0 \sum n \delta_{mn} \frac{\delta P}{B} \sin(m\theta - n\phi)$$

  - Benchmarking test of NTV calculation with theory is underway
  - Calculated NTV torque profile shows very similar shape with theory revealing resonant and non-resonant features, but discrepancies still exist depending on collisionality
  - Under investigating possible reasons (physics or numerical?)



$\delta_{mn} = 0.02\ \psi_n^2$

$\nu^* \sim 0.05$
$\nu^* \sim 0.5$
$\nu^* \sim 1.0$
$\nu^* \sim 2.0$
$\nu^* \sim 5.0$

Symbol: POCA
Solid: Theory*

**J.-K. Park et al, Phys. Rev. Lett., 102, 065002 (1984)*

POCA will be upgraded to be applicable for experimental analysis and integrated with IPEC (GPEC)

- POCA will be extended to experimental analysis
  - POCA can read geqdsk file for 2D equilibrium and combine with 3D magnetic perturbation from IPEC
  - With temperature and density profiles, POCA will be able to calculate NTV torque and rotation damping in NSTX(-U) and other tokamaks
  - Presently, ExB shear rotation and potential are neglected, but will be included in the near future
- POCA will be integrated to GPEC (General Perturbed Equilibrium Code)
  - GPEC will solve 3D force balance with general jump conditions at the layer and tensor pressure (or general force)
  - POCA will provide non-ideal tensor pressure to GPEC
- Technical issues remain
  - POCA was parallelized with MPI but there is still room for improvement of computational efficiency (e.g. interpolating magnetic field information, optimizing code structure)
  - Need to properly define the annulus width, which could affect calculation results

- POCA will be ready to support the analysis of 3D physics in NSTX-U

GPEC will provide free-boundary perturbed tokamak equilibria, with arbitrary force and jump conditions

- IPEC uses perturbed scalar pressure force and ideal jump conditions

$$\vec{\nabla}\delta p = \delta\vec{j}\times\vec{B} + \vec{j}\times\delta\vec{B} \ \text{ with } \ \left(\delta\vec{B}\cdot\vec{\nabla}\psi\right)_{mn} = 0$$

- GPEC will use any perturbed force and general jump conditions

$$\delta\vec{f} = \delta\vec{j}\times\vec{B} + \vec{j}\times\delta\vec{B} \ \text{ with given} \left(1 \text{ or } \frac{d}{d\psi}\bigg|\right)\left(\delta\vec{B}\cdot\vec{\nabla}\psi\right)_{mn}$$

- Presently, large resonant solutions were resolved by solving force balance in the ‘field’ frame, rather than the ‘displacement’ frame. So now we can solve

$$\vec{\nabla}\delta p = \delta\vec{j}\times\vec{B} + \vec{j}\times\delta\vec{B} \ \text{ with given} \left(1 \text{ or } \frac{d}{d\psi}\bigg|\right)\left(\delta\vec{B}\cdot\vec{\nabla}\psi\right)_{mn}$$

This version can provide linear resistive stability, such as tearing mode index with full coupling or with external 3D fields, and perturbed equilibria with partially or fully opened islands, etc

- Next, perturbed anisotropic pressure force and layer conditions will be included

$$\underbrace{\vec{\nabla}\cdot\left(\delta p_\perp\vec{I} + \left(\delta p_\parallel - \delta p_\perp\right)\hat{b}\hat{b}\right)}_{\textit{POCA (or theory)}} = \delta\vec{j}\times\vec{B} + \vec{j}\times\delta\vec{B} \ \underbrace{\text{with given} \left(1 \text{ or } \frac{d}{d\psi}\bigg|\right)\left(\delta\vec{B}\cdot\vec{\nabla}\psi\right)_{mn}}_{\textit{Layer theory by Rutherford, Boozer, Fitzpatrick, or an inner-layer solver}}$$